Impact of Ramadan on Physical Activity and Sleeping Patterns in Individuals with Type 2 Diabetes: The First Study Using Fitbit Device

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ABSTRACT

Introduction: The impact of Ramadan fasting, a type of intermittent fasting, on the management of diabetes has not been well investigated. Physical activity, sleep duration, and time of sleep are susceptible to alterations during Ramadan due to the changes in the times and numbers of meals. This study compared physical activity and sleep patterns of individuals with type 2 diabetes mellitus (T2DM) during and after Ramadan using the international physical activity questionnaire (IPAQ) and a Fitbit Flex 2 accelerometer.

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Methods: Saudi individuals ($n = 36$) with T2DM completed a self-reported questionnaire and wore a Fitbit device for seven consecutive days during and after Ramadan. Fitbit generated weekly step counts, activity intensities, sedentary time, and sleep durations and times. IPAQ was used to estimate the physical activity and sitting time of participants in each period. Sleep patterns were assessed in each period by a self-reported questionnaire.

Results: Both Fitbit and IPAQ indicated a high prevalence of low physical activity among the participants with non-significant variances between the during and after Ramadan periods. Also, a significant short daily total sleeping hours and daily night-time sleeping hours was seen during the Ramadan period. The duration of night-time sleep was observed to be low in each period.

Conclusions: This is the first study to use a Fitbit device to monitor individuals with T2DM who chose to fast during Ramadan. The study shows a high prevalence of low physical activity among Saudi individuals with T2DM in each period, and short sleep durations in the during Ramadan period compared to after Ramadan period. A high prevalence of short night-time sleep duration and excessive daytime sleeping was observed in both periods and significantly in the during Ramadan period. A larger study is needed in the future covering before, during, and after Ramadan to evaluate the impact of lifestyle changes related to Ramadan fasting on type 2 diabetes.

Key Summary Points
Why carry out this study?
Saudi Arabia has one of the highest prevalences of diabetes in the world with over 30% of its population affected by type 2 diabetes. This has negative impacts on the lives of individuals and is a great burden on the healthcare system and the economy of the country.
Physical activity and sleeping patterns are important factors for managing diabetes. These are susceptible to alterations during the month of Ramadan when most adult Saudis perform a type of intermittent fasting, from dawn till dusk for 29–30 days. How Ramadan fasting alters sleeping and physical activity of Saudis with type 2 diabetes has not been well investigated.
What was learned from the study?
High prevalence of physical inactivity among study participants is a cause for concern and further research is needed in this area with a larger population.
Short sleeping duration during Ramadan and prevalence of short night-time sleep after Ramadan may have adverse effects on the health of individuals with type 2 diabetes which needs to be further investigated.

INTRODUCTION

Diabetes mellitus is a common chronic disease, which has been estimated to affect 31.6% of the Saudi population [1]. Different factors, such as environmental, social, and lifestyle factors, have been linked with the treatment and incidence of type 2 diabetes mellitus (T2DM). For instance, several studies have demonstrated that increased physical activity and enhanced sleep quality are essential factors for better outcomes in the control of T2DM [2–6]. Increased physical activity has been reported to be correlated with reduced HbA1c and glycaemic levels, and decreased cardiovascular complications among individuals with T2DM [7–9]. The benefits of physical activity on T2DM have been shown through the significant improvements in the sensitivity of insulin [10]. However, physical inactivity can increase the susceptibility of developing of T2DM or worsen the diabetic condition in individuals who are already suffering from this condition [3, 6, 11]. Unfortunately, physical inactivity has been reported to be common among the Saudi population, where the General Authority for Statistics in Saudi Arabia recently reported that only 17.4% of Saudis are performing physical activity for 150 min or more per week [12].

For the sleep quality, both long and short sleep durations have been previously reported to be associated with increased HbA1c levels [13, 14]. Sleep during the night-time is important for the metabolic process, which has been shown to facilitate blood glucose regulation that is essential for diabetes outcomes [15]. Short duration of sleeping during the night-time has been observed among a portion of the Saudi population [16, 17]. In addition, numerous studies have shown that the disturbance of the circadian rhythm can cause T2DM or make it worsen through affecting glucose homeostasis, insulin secretion, and insulin sensitivity [18–20].

The month of Ramadan is the ninth month in the lunar year, in which healthy adult Muslims abstain from any type of food, drink, or medicine administered through the mouth, smoking, and sexual interaction from dawn to dusk each day for 29 or 30 days [21]. As a result of some activities during the month of Ramadan and changes in the numbers and times of meals, Ramadan has been reported to be associated with alterations in sleeping durations and times, and physical activities [22–27]. These changes may affect public health, and

particularly individuals with diabetes. At worst, these may minimise the achievement of optimal positive impact of intermittent fasting during Ramadan, which has been previously reported to be beneficial for T2DM [28–31]. Therefore, the investigation of the physical activity and sleeping patterns of Muslim individuals with T2DM during Ramadan, using a precise measurement tool, is needed to help understand the impact of Ramadan fasting. However, the precise measurement of the complex set of behaviours such as physical activity and sleeping patterns is not easy as self-reported questionnaires, which are the most common measurement tools, are susceptible to recall bias and misreporting [32–34]. Wearable devices such as Fitbit have been previously reported to provide reliable assessment of physical activity and sleep [35, 36]. Hence, this study aimed to investigate and evaluate the physical activity and sleeping patterns of Saudi individuals with type 2 diabetes during and after Ramadan periods using the Fitbit device and a questionnaire. The outcomes of physical activity and sleeping patterns during the Ramadan period were compared to those in the after Ramadan period. In addition, the outcomes of each method were correlated with those of the other method, and the significance and direction of these correlations were evaluated.

METHODOLOGY

Study Settings and Design

This was an exploratory pilot study conducted over two periods (during and after Ramadan). In this study, 36 adult Muslims with T2DM, who had an intention to fast during Ramadan, were recruited during their routine visits to the Endocrine and Diabetic Centre of Al Iman General Hospital, Riyadh, Saudi Arabia. The during Ramadan visit occurred in the middle of the month of Ramadan [29 May–14 June, 2018], and the after Ramadan visit was arranged 2 weeks after the end of the month of Ramadan [29 Jun–13 July, 2018]. Informed consent was obtained from each participant prior to commencement of the study. Baseline demographic data was collected in the during Ramadan visit. Self-reported baseline demographic data were collected from each participant. In each period, two different techniques, namely self-reported questionnaire and Fitbit Flex 2 accelerometer (Fitbit Inc., San Francisco, CA), were used to assess the physical activity and sleeping patterns of the participants. Along with physical measurements for each participant, blood samples after 12 h of fasting were obtained for laboratory analysis.

Data Collection and Measurements

Demographic Data
Demographic data were collected by self-reported questionnaire in the first visit. Demographic data included age, gender, marital status, employment status, and duration of T2DM.

Physical and Laboratory Measurements
In each period, height (to the nearest 0.5 cm), weight (to the nearest 0.1 kg), and waist size (to the nearest 0.5 cm) were measured for each participant. The waist size was measured with a tape placed in the middle between the lower margin of the ribs and the superior border of the iliac crest. Body mass index (BMI) was calculated for each participant, using the ratio of weight (in kilograms) to the height (in metres) squared. Blood samples were determined in the main laboratory of Al Iman General Hospital for measuring HbA1c. All blood samples were analysed using a biochemical analyser (Dimension RxL Max®, Siemens Medical Solution Diagnostics, Tarrytown, NY) in accordance with the instructions provided by the manufacturer.

Physical Activity
Physical activity data for weekly step counts, different intensity of activity, walking, and sedentary and sitting times were measured using a Fitbit Flex 2 accelerometer and a self-reported questionnaire. The self-reported questionnaire was supported by using the Arabic version of the short form of the international physical activity questionnaire (IPAQ).

Fitbit Device

The Fitbit Flex 2 accelerometer is a wearable and waterproof device that tracks physical activity and sleep, and can store data for 7 days without syncing [37]. Each device was linked to an account created on the Fitbit website (https://www.fitbit.com), and the saved data were exported from the Fitbit online dashboard. The active minutes of 10 min duration or more are calculated by Fitbit as metabolic equivalents (METs) and presented in minutes per week. Each participant was asked to wear the Fitbit Flex 2 device for seven consecutive days before each visit (during and after Ramadan). Participants were informed to wear the device all the time during each period, and to keep their regular activities. In addition, no instructions or specific goals were given to the participants regarding their physical activities or sleep. Raw Fitbit data of 7 days were collected at the end of each period. The raw data included step counts, low activity, moderate activity, vigorous activity, and sedentary time. After collecting all the required data, all accounts were deleted from the Fitbit website and all devices were reset to avoid further data collection.

IPAQ

IPAQ was created in 1997 as an observational measurement to assess physical activity, which was validated and reported with high reliability [38, 39]. The short form of IPAQ is composed of seven questions that are used to estimate the time spent per week performing different intensities of physical activity. This physical activity can be categorized according to its intensity, whether vigorous, moderate, or low. These categories are estimated using a metabolic equivalent (MET) value and presented as MET-min/week. The IPAQ estimates the types of the intensity of physical activity, walking, and sitting time of participants during a usual week.

Sleeping Patterns

A self-reported questionnaire with closed-ended questions was used in each period to assess the sleeping patterns of participants through asking about the total number of sleeping hours per day, the number of night-time sleeping hours, and the total number of hours spent sleeping daily. In addition, the Fitbit Flex 2 accelerometer was used to record sleep durations and times for each participant in each period. The sleep data from the Fitbit device was obtained by recording the duration of sleep between sunset and sunrise, according to the location of the study. This was considered as night-time sleep for each participant. Consequently, the daily averages of total sleeping hours and night-time sleeping hours were calculated for each participant. In addition, the average daily total sleeping hours and average daily night-time sleeping hours were organised into different categories.

Statistical Analysis

Statistical analysis was performed using SPSS software version 25 (IBM Corporation, Armonk, NY, USA). Descriptive statistics analysis was applied for outcomes where mean ± standard deviation (SD) was used for normally distributed continuous variables, median and interquartile range (IQR) was used for non-normally distributed continuous variables, and counts and percentages were used for categorical variables. The normality of each continuous variable was assessed. For the normally distributed variable, paired t test was applied to compare two variables between the two periods, and one-way ANOVA was used to detect variances between groups. For the non-normally distributed variables, non-parametric tests such as Wilcoxon and Spearman correlation were used in the analysis. The effect size (r) was also calculated to measure the magnitude of the differences between periods. This effect size (ES) was calculated by the following formula: $r = Z/\sqrt{n}$ (where $Z = z$ score produced by Wilcoxon signed rank test and n = total sample size). The obtained ES was reported according to Cohen's [40] guidelines (0.1, 0.3, and 0.5 indicating small, moderate, and large effects, respectively). A chi-square test was used to compare the variance in the proportion between categorical variables. If any cell of the chi-square test was less than 5, the Fisher's exact test was conducted. The statistical significance level for all two-tailed tests was set at $P < 0.05$.

Ethical approvals were obtained from the Faculty of Health and Life Sciences Research Ethics Committee at De Montfort University and the Ministry of Health in Saudi Arabia. All procedures followed were in accordance with the Helsinki Declaration of 1964 and its later amendments. Informed consent was obtained from each participant prior to commencement of the study to take part in this study and for any publication with non-identifiable quotes.

RESULTS

The baseline sociodemographic characteristics of the 36 participants are presented in Table 1, of whom 55.6% ($n = 20$) were men and 44.4% ($n = 16$) were women. The mean age $\pm$ SD of the participants was 49.50 ± 11.91 years. Fifty percent of participants were aged 41–60 years and 80.6% of the participants were married. There was a significant variance between genders regarding their employment status ($x^2 = 15.59$; $P < 0.001$), as most of the employed participants were men. The mean duration of having T2DM was 10.92 ± 8.88 years for the total study sample.

Table 2 demonstrates the comparisons of the physical measurements and laboratory results of the participants between the during and after Ramadan periods. No significant variances were found between the during and after Ramadan periods in the means of weight, BMI, waist size, and HbA1c levels. Only one participant had normal BMI, while more than half of the participants were obese. Interestingly, HbA1c levels during Ramadan were lower than in the after Ramadan period but the difference was neither statistically significant nor clinically important.

The comparisons of the obtained data regarding the physical activities from IPAQ and Fitbit Flex 2 in the two different periods are shown in Table 3. The Wilcoxon signed ranks tests revealed no statistically significant variances between the during and after Ramadan periods in all types of participants' activities and sitting or sedentary times with very small effect sizes. However, the difference between periods in the total activity (vigorous + moderate + walking) measured by IPAQ was

statistically significant ($P = 0.029$) but with small ES ($r = 0.257$). Although the levels of the majority of participants were low according to IPAQ in both periods, the during Ramadan period showed slightly higher physical activity but was not significant compared to the after Ramadan period ($P = 0.560$). Low level of physical activity was observed in at least 69.4% of participants in each period.

Table 4 presents the Spearman's rank correlations between the physical activity outcomes of the Fitbit and the IPAQ in each period. The analysis revealed that there were strong positive significant correlations between vigorous activities and moderate activities measured by Fitbit Flex 2 and IPAQ during Ramadan that became moderate correlations in the after Ramadan period. The step counts by Fitbit strongly correlated with the walking measured by IPAQ in each period (during and after Ramadan). For the sedentary and sitting times, there were moderate correlations between the measurements of Fitbit and IPAQ in each period (during and after Ramadan). In addition, the sedentary and sitting times measured by the Fitbit and the IPAQ negatively correlated with all other activity types in each period. The daily average of sitting and sedentary times, measured by both instruments, were at least 10 h in each period. In addition, the sitting time obtained by the IPAQ was under-reported by participants compared to sedentary time collected by Fitbit Flex 2 in each period ($P < 0.05$).

The outcomes regarding sleeping patterns of participants, reported by questionnaire and recorded by Fitbit Flex 2, are shown in Table 5. The statistical analysis demonstrates significant differences between the during Ramadan and after Ramadan periods in the sleeping patterns measured by both methods, with reduced sleeping hours during the Ramadan period. According to the Fitbit, the median daily total sleeping hours significantly increased in the after Ramadan period compared to the during Ramadan period (7.02 h vs 6.03 h; $P < 0.001$), with moderate ES ($r = 0.457$). The average daily total sleeping hours of less than 6 h, recorded by Fitbit, was observed in 50% of participants during Ramadan and in 13.9% after Ramadan. Interestingly, half or more of participants did

Table 1 Baseline sociodemographic characteristics of participants ($n = 36$)

Outcomes	Mean ± SD or n (%)			P value
	Total ($n = 36$)	Male ($n = 20$)	Female ($n = 16$)	
Age (years)	49.50 ± 11.91	49.25 ± 11.48	49.81 ± 12.80	0.890
Age group (years)				
≤ 40	9 (25%)	4 (20%)	5 (31.3%)	0.457*
41–60	18 (50%)	12 (60%)	6 (37.5%)	
> 60	9 (25%)	4 (20%)	5 (31.3%)	
Diabetes duration (years)	10.92 ± 8.88	10.35 ± 8.57	11.63 ± 9.50	0.675
Marital status				
Married	29 (80.6%)	18 (90%)	11 (68.8%)	0.060*
Single	3 (8.3%)	2 (10%)	1 (6.3%)	
Divorced/widowed	4 (11.1%)	0 (0.0)	4 (25%)	
Employment status				
Employed	13 (36.1%)	11 (55%)	2 (12.5%)	< 0.001*
Unemployed	16 (44.4%)	3 (15%)	13 (81.3%)	
Retired	7 (19.4%)	6 (30%)	1 (6.3%)	

P values of the unpaired t tests for continuous variables or of the chi-square test for categorical variables

*A Fisher's exact test was applied if any cell of chi-square test was < 5

Table 2 Comparisons of physical measurements and laboratory results of the participants between the during and after Ramadan periods ($n = 36$)

	Mean ± SD or n (%)		95% CI	P value
	During Ramadan	After Ramadan		
Weight (kg)	85.76 ± 17.38	85.73 ± 16.01	− 2.13 to 2.07	0.976
BMI	32.89 ± 5.47	32.94 ± 5.12	− 0.71 to 0.81	0.892
BMI categories				
Normal	1 (2.78%)	1 (2.78%)		1.000*
Overweight	13 (36.11%)	14 (38.89%)		
Obese	22 (61.11%)	21 (58.33%)		
Waist size (cm)	107.00 ± 11.78	106.10 ± 11.15	− 2.60 to 0.82	0.296
HbA1c (%)	7.81 ± 1.40	7.92 ± 1.38	− 0.02 to 0.23	0.108

P values of the paired t tests for continuous variables and of the chi-square test for categorical variables

SD standard deviation, *CI* confidence intervals, *BMI* body mass index, *HbA1c* glycated haemoglobin

*A Fisher's exact test was applied if any cell of chi-square test was < 5

Table 3 Comparisons between the physical activity outcomes measured by IPAQ and Fitbit Flex 2 for participants in the two different periods (during and after Ramadan, $n = 36$)

Outcomes	Median (IQR) or n (%)		P value	SE (r)
	During Ramadan	**After Ramadan**		
IPAQ (MET-min/week)				
Vigorous activity	0 (0–240)	0 (0–240)	0.095	0.196
Moderate activity	120 (40–180)	120 (40–120)	0.160	0.166
Walking activity	396 (297–495)	396 (231–495)	0.882	0.018
Total (vigorous + moderate + walking)	676 (414–930)	516 (351–855)	0.029	0.257
Sitting time (h/week)	74 (70–88)	73.5 (63–87.5)	0.750	0.037
IPAQ level				
Low	25 (69.4%)	28 (77.8%)	0.560	
Moderate	7 (19.4%)	5 (13.9%)		
High	4 (11.1%)	3 (8.3%)		
Fitbit Flex 2 (min/week)				
Vigorous activity	148 (0–204)	66 (0–141)	0.092	0.199
Moderate activity	70 (30–209)	116 (38–202)	0.829	0.025
Low activity	1403 (1104–1819)	1559 (1139–1726)	0.203	0.150
Steps per week	32,170 (28,953–55,632)	36,681 (28,449–50,964)	0.326	0.116
Total (vigorous + moderate + low + steps)	34,084 (30,157–57,787)	38,480 (29,612–52,979)	0.451	0.089
Sedentary (h/week)	97 (92.3–118)	99.5 (88–102)	0.102	0.193

P values for nonparametric paired Wilcoxon signed ranks tests

IPAQ international physical activity questionnaire, *MET* metabolic equivalents, *n* number, *IQR* interquartile range, *ES (r)* effect size *r*

not report any instances of all sleeping being at night-time during the Ramadan period by both measurement methods. In the after Ramadan period, sleeping during night-time significantly increased compared to during Ramadan, with moderate ES ($r = 0.439$). However, it was still low with sleeping of less than 3 h at night-time being reported by 33.33% of participants in the questionnaire and 77.8% in the Fitbit. The statistical analysis did not detect significant correlations between the average daily total sleeping hours, recorded by Fitbit and reported in the questionnaire, during and after Ramadan periods ($r_s = 0.321$, $n = 36$, $P = 0.056$ and $r_s = 0.242$, $n = 36$, $P = 0.155$, respectively).

Additionally, all these non-significant correlations were week correlations. Likewise, the average daily night-time sleeping hours, recorded by the Fitbit, did not significantly correlate to that reported by questionnaire in the during and after Ramadan periods ($r_s = 0.212$, $n = 36$, $P = 0.214$ and $r_s = 0.235$, $n = 36$, $P = 0.169$, respectively). Furthermore, all these non-significant correlations were week correlations. From the former analysis and correlations, there was over-reporting of outcomes by participants in the questionnaire compared to Fitbit outcomes regarding their daily total sleeping hours and daily night-time sleeping hours in both periods (during and after Ramadan).

Table 4 Spearman's rank correlations coefficients (r_s) between the physical activity outcomes measured by Fitbit Flex 2 and IPAQ in each period (during and after Ramadan, $n = 36$)

| | During Ramadan | | | | After Ramadan | | | |
| | IPAQ | | | | IPAQ | | | |
	Vigorous activity	Moderate activity	Walking	Sitting (h/week)	Vigorous activity	Moderate activity	Walking	Sitting (h/week)
Fitbit Flex 2								
Vigorous activity	0.643*	0.507*	0.200	− 0.225	0.341*	0.250	0.711**	− 0.233
Moderate activity	0.131	0.792*	0.502*	− 0.461*	0.242	0.452*	0.643*	− 0.353*
Steps (per week)	0.249	0.637*	0.743*	− 0.474*	0.343*	0.511*	0.806*	− 0.396*
Sedentary (h/week)	− 0.189	− 0.397*	− 0.541*	0.344*	− 0.207	− 0.401*	− 0.436*	0.460*

IPAQ international physical activity questionnaire, *MET* metabolic equivalents

*Correlation is significant with $P < 0.05$

Independent t test and one-way ANOVA tests did not detect any statistically significant variances between genders, age groups, marital status, and employment status in the total activity measured by both methods for each period ($P > 0.05$). Similarly, no statistically significant differences were detected in mean HbA1c levels between different IPAQ levels, i.e. low, moderate, and high ($P > 0.05$). Furthermore, mean HbA1c levels did not significantly vary between different sleeping patterns reported by both methods in each period. Interestingly, Spearman's rank indicated that HbA1c levels negatively but not-significantly correlated with the total activity by IPAQ during and after Ramadan, and total activity by Fitbit during and after Ramadan periods ($P = 0.394$, $P = 0.766$, $P = 0.695$, and $P = 0.680$; respectively).

DISCUSSION

Ramadan fasting is a type of intermittent fasting that is performed for 1 month by Muslims around the world. Although intermittent fasting has been reported to have diverse health benefits [41–45], research on Ramadan fasting is limited. Our study reveals a high prevalence of physical inactivity among participants in the during and after Ramadan periods obtained by a wearable device (Fitbit) and a self-reported questionnaire. In addition, a high prevalence of sedentary and sitting times was recorded by both methods in each period. These findings are of concern since it has been previously reported that these behaviours negatively impact on the management and treatment of diabetes [3, 6], or are linked to the development of T2DM [11, 46]. Moreover, a positive correlation was found between increased sedentary time and some risk factors of developing T2DM such as increased waist size and BMI [47]. In contrast, increased daily steps, which are considered a type of physical activity, was reported to be associated with reduced HbA1c levels [9]. Physical activity can increase glucose uptake by muscles and organs of the body in order to produce energy without the need for insulin [48].

Our findings of a high prevalence of physical inactivity and increased sedentary time are consistent with previous studies that have reported low physical activity among Saudis.

Table 5 Comparisons between the sleeping outcomes collected by questionnaire and Fitbit Flex 2 for participants in the two different periods (during and after Ramadan, $n = 36$)

Outcomes	Period [median (IQR) or n (%)]		P value
	During Ramadan	After Ramadan	
Questionnaire (h)			
Daily total sleeping hours			
< 6	4 (11.1%)	2 (5.6%)	0.007
6–8	27 (75%)	18 (50%)	
> 8	5 (13.9%)	16 (44.4%)	
Daily night-time sleeping hours			
Never	20 (55.6%)	3 (8.3%)	0.005
> 3	5 (13.9%)	9 (25%)	
3–6	6 (16.7%)	14 (38.9%)	
> 6	5 (13.9%)	10 (27.8%)	
Fitbit Flex 2 (h)			
Average daily total sleeping hours (h)	6.03 (5.37–6.67)	7.02 (6.35–7.71)	< 0.001
Average daily total sleeping hours categories			
< 6	18 (50%)	5 (13.9%)	< 0.001
6–8	17 (47.2%)	25 (69.4%)	
> 8	1 (2.8%)	6 (16.7%)	
Average daily night-time sleeping hours (h)	0 (0–1.30)	1.78 (0.67–2.88)	< 0.001
Average daily night-time sleeping hours categories			
Never	18 (50%)	6 (16.7%)	< 0.001
> 3	17 (47.2%)	22 (61.1%)	
3–6	1 (2.8%)	7 (19.4%)	
> 6	0 (0%)	1 (2.8%)	

P values for non-parametric paired Wilcoxon signed-rank tests

SD standard deviation, n number

For example, the Saudi General Authority for Statistics reported that 82.6% of Saudis did not practice physical activity for 150 min or more per week in 2018 [12]. Furthermore, the World Health Organization (WHO) reported in 2016 that the prevalence of physical inactivity in the Saudi population was 58.5% [49].

The high prevalence of physical inactivity and high sedentary time observed in the current study could be attributed to some barriers. For instance, the climate has been previously found

by Amin et al. [50] to be an obstacle for 65.9% of Saudis to perform physical activity. In addition, climate prevented outdoor activity in 80% of Saudi individuals with T2DM in Riyadh [51]. The climate prevents people from performing physical activity, especially outdoor activities, because of the hot temperature outside. However, the establishment of community sports centres with adapted indoor temperature can minimise the negative impact of climate on physical activity. Unfortunately, the lack of these centres has been reported as a barrier to performing physical activity among Saudis [52, 53], which could be another possible explanation for the finding of this study for the low level of physical activity. Furthermore, the lack of time in Saudis has been reported by previous researchers as a barrier for performing physical activity [50, 52]. Another potential impediment could be urbanisation [52, 54], whereby Saudis living in villages were found to be more physically active than who live in cities, which can be attributed to the participation in some farming tasks such as ploughing and planting [55].

Another interesting finding of the current study is that no statistically significant differences in physical activity were detected between the during and after Ramadan periods, which agrees with previous studies that did not report changes in physical activity of individuals with T2DM during Ramadan [31, 56]. In healthy individuals from Riyadh, no differences were observed in their physical activity during Ramadan compared to before or after Ramadan [57]. Although the current study did not detect significant differences in the participants' activities between periods, physical activity during Ramadan was slightly higher than in the after Ramadan period. A similar finding has been reported by Sfar et al. [58], who showed a non-significant increase in physical activity of Tunisian individuals with T2DM during Ramadan compared to the pre-Ramadan period. In addition, the total activity measured by IPAQ showed a significant increase during Ramadan in this study compared to the after Ramadan period, but with small effect size. This non-significant increase of physical activity during Ramadan could be attributed to the increase in

prayer activities such as Taraweeh prayers, additional ritual prayers performed by Muslims at night during Ramadan, which was previously suggested as a form of "physical activity" due to the long hours of standing during prayers [59]. However, there is the possibility that the "after" Ramadan results are not much different because a 2-week period may not be enough to change behaviours.

The current study showed strong positive correlations between the measurements of physical activity by IPAQ and Fitbit Flex 2 accelerometer. In addition, previous studies have reported that Fitbit devices are quite reliable for assessing physical activity [35, 36, 60, 61]. Hence, this finding of the current study reveals that the IPAQ was acceptable and reliable for measuring the physical activity of its participants. However, this study also indicated that the sitting time measured by IPAQ was under-reported by participants compared to the sedentary time measured by the Fitbit device. This could be due to misreporting, because a previous study concluded that the sitting time determined by IPAQ was under-reported by the study population when compared to the sedentary time recorded by an accelerometer [62]. In addition, self-reported surveys are susceptible to underestimating or misreporting of the sedentary time by the participants as a result of recall bias [63, 64].

The statistical analysis of the current study detected significant differences between the during and after Ramadan periods in the sleeping hours obtained by both instruments. These differences in the current study were observed with significantly shorter sleeping hours during Ramadan compared to the after Ramadan period. Although 7–8 h of daily sleeping is the recommended duration for optimal health [13, 65, 66], the daily average of sleeping among half the participants during Ramadan was less than 6 h. This finding agrees with the previous studies that reported a reduction in sleep durations during Ramadan [22, 24, 67, 68]. Furthermore, insufficient sleep duration of less than 8 h has been previously observed among 95% of the participants of a study conducted on Saudi female students from a college in Riyadh [69]. The amount of sleeping at night-time,

reported by the latter study, was found to be low in both periods. The duration of night-time sleep significantly rose after Ramadan compared to the during Ramadan period. Previous studies have demonstrated similar findings of short amounts of night-time sleep during Ramadan [25–27], and short night-time sleep duration and excessive daytime tiredness among the Saudi population is not only limited to the month of Ramadan but is seen throughout the year [16, 17].

The changes in meals times, because Muslims abstain from eating and drinking during the daytime of Ramadan, could be the possible reason for the shortened sleep duration during Ramadan especially at night-time [22]. In addition, other environmental factors, such as higher daytime temperature, and stores and shopping malls remaining open until late during the Ramadan period could be considered as other possible explanations for the shortened night-time sleep during Ramadan. The practice of additional worships including Taraweeh prayers during the night-time of Ramadan could be another possible reason for this finding. Hence, the shortened night-time sleep during Ramadan could be the reason behind the shortened daily total sleeping hours during Ramadan compared to the after Ramadan period. The after Ramadan period of the current study occurred during the summer holiday, in which the longer night-time is usually spent with family and friends because of the events and parties, which is a likely explanation for the short night-time sleep hours in this period.

Although the self-reported method for sleep quality has been previously found to be positively correlated with the data obtained by Fitbit [61], the current study did not detect significant correlations between both methods in each period. The participants of the current study overestimated their sleeping hours in the questionnaires compared to the results recorded by the Fitbit devices. This contradictory finding is likely because the measurement of sleep is prone to recall bias and misreporting by participants in self-reported measures [64]. However, it is important to note that these explanations do not absolutely mean that Fitbit measurements are accurate; they have been previously reported to have insufficient accuracy in assessing sleep patterns compared to polysomnography [70].

This study demonstrated that the means of HbA1c levels were more than 7% in each period, which is considered as poor glycaemic control according to the guidelines of the American Diabetes Association [71]. The observed behaviours of physical inactivity and poor sleeping pattern could be one of the possible reasons behind this poor control. Additionally, the mean HbA1c levels were lower in the during Ramadan compared to after Ramadan period although the change is neither statistically significant nor clinically important. Previous studies have reported that intermittent fasting is beneficial for individuals with T2DM [41–43], and reversed T2DM in some cases [44, 45]. The month of Ramadan involves a type of religious intermittent fasting, when Muslims abstain from eating, drinking, smoking, and sexual interaction from dawn to dusk for 29 or 30 days [21], which also has been previously reported to have a positive impact on T2DM [28–31]. However, the month of Ramadan is associated with significant changes in lifestyle, such as altered sleeping durations and times and changes in physical activities [22, 24]. Indeed, physical activity and sleeping quality have been demonstrated by numerous studies as important factors that influence the outcomes of T2DM [2–6]. Increased physical activity has been indicated to be associated with reduced HbA1c levels [9]. In addition, the disturbance of the circadian rhythm has been previously reported to be a risk factor for developing T2DM by causing insulin resistance [19, 20]. Makino et al. [72] reported that night-time sleeping hours of less than 5 h per night were positively correlated with an increase in HbA1c levels in Japanese individuals with T2DM when compared to longer night-time sleeping hours. In line with these findings, it can be concluded that decrease in sleeping hours during Ramadan, observed in our study, could minimize the positive impact of fasting on people with T2DM. However, it is possible that the 2-week period after the end of Ramadan, when HbA1c was measured, might not be enough to detect significant differences.

STRENGTHS

To the best of our knowledge, this study is the first to investigate and evaluate the physical activity and sleeping patterns of individuals with type 2 diabetes fasting in the during and after Ramadan periods, using subjective and objective techniques (IPAQ and Fitbit Flex 2). The application of wearable technology to assess changes in lifestyle during Ramadan fasting can help individuals and health professionals to efficiently track or monitor physical activity and sleep patterns, and to generate accurate and reliable results for the management of disease and improve public health.

LIMITATIONS

Unfortunately, this study is subject to some limitations. Since the current study was an exploratory pilot study with a relatively small sample size, it has limited statistical power. However, the obtained results are highly informative and call for further cohort studies to verify the importance of the findings of the current study. In addition, it is not possible to confirm that every participant used the Fitbit device properly for the entire study duration, or each device recorded or synced all activities, which could affect the overall results. Moreover, as with most self-reported measurements, the questionnaires used in this study were also subject to bias, which affected the reliability of the results. For example, the participants reported that they fasted during Ramadan but there is no way of verifying if this is true as fasting is a very personal matter. Furthermore, the used questionnaires for the assessment of sleep patterns may not have been sufficient. Additionally, although the participants recruited were Saudis from Riyadh, the small sample size means that they are not representative of the entire Saudi population diagnosed with T2DM. For this to be the case, more participants from different regions of Saudi Arabia would have been required for further cohort studies. Another important limitation was the lack of a control group, as this would add strong evidence to the overall conclusion. In addition, a 2-week period after the end of Ramadan may not be sufficient to detect significant changes. The before Ramadan period was unfortunately missed since the ethical approval was obtained later. Therefore, conducting a larger cohort study that includes measurements before, during, and after Ramadan could provide a better picture about how these behaviours change (or not) as a result of fasting.

CONCLUSIONS

This is the first study to combine a wearable device (Fitbit) and a self-reported questionnaire to monitor physical activity and sleeping patterns in individuals with T2D who chose to fast during the month of Ramadan. We can conclude that a high prevalence of physical inactivity was noticed among individuals with T2DM in the during and after Ramadan periods, with no significant differences between these periods regarding their physical activity. This study also indicates that the daily total sleeping hours significantly varied between the during and after Ramadan periods, with significantly shorter sleep durations observed in the during Ramadan fasting period. Although the prevalence of short night-time sleeping hours was nevertheless high for most individuals in both periods, the during Ramadan period showed significant short night-time sleeping hours. In addition, this study reveals that the data recorded by the Fitbit Flex 2 accelerometer were significantly correlated with the self-reported outcomes obtained by IPAQ for the physical activity of individuals, but not for sleeping patterns collected by a self-reported questionnaire. Therefore, the low physical activity and the poor sleep behaviours of the study's participants may worsen their diabetes, and minimise the potential of Ramadan intermittent fasting as a non-pharmacological therapy for management of T2DM. A larger study is needed in the future covering before, during, and after Ramadan to fully assess the impact of Ramadan on T2DM.

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